Observations of Jupiter's Synchrotrons Radiation at 18 cm during the Comet SL-9 Impacts

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Abstract

The results of observations of Jupiter's synchrotrons radiation during the period surrounding the impacts of comet SL-9 are reported. The observations were made at the Naval Research Laboratory's Maryland Point Observatory 85 foot radio antenna operating at 1665 MHz (18 cm). The data indicate that an increase in the intensity of the synchrotrons emission of 23% took place over the full duration of the impact period. The increase was accompanied by two characteristic changes in the beaming curve: a flattening and the creation of brightness temperature variations on hourly timescales. We interpret the latter as longitudinal variations in the beaming curve which suggests a localized mechanism resulting in a redistribution of the radiating electrons in the Jovian radiation belts.

Introduction

The predicted impacts of comet Shoemaker-Levy 9 with Jupiter provided a unique experiment in nature for radio astronomers to observe. Of interest was the opportunity to study the affects on Jupiter's radiation belts and magnetosphere. The observations reported in this paper were made using the Naval Research Laboratory's 85-foot (26 m) telescope operating at 1665 MHz (18 cm). The observing program was originally planned in 1993 to search for short term variations (days to weeks) in Jupiter's synchrotrons radiation. Our planned initial startup date of June 1994 was fortunate as the discovery of the comet fragment impacts provided an exciting opportunity to begin our program with.

Jupiter's synchrotrons radiation has exhibited an indisputable variability on a time scale of years (Klein et al. 1989). Previous studies have shown these long term variations to be well correlated with the solar wind with an approximate 2 year delay (Bolton et al. 1989). The 2 year delay is consistent with theoretical estimates of inward radial diffusion time scales. (Brice 1972, Coroniti 1974). Observations by Gerard (1970), Klein et al. (1989) and Bolton (1990) showed possible short term variability but the observations

remained unconfirmed. The worldwide network of radio astronomers organized for the comet impact event provided the first opportunity for multiple telescopes to observe Jupiter for a significant period of time. The results reported in this paper describe the changes to Jupiter's high energy radiation belts associated with the comet impacts and are consistent with the preliminary results from other observers (Klein et al. 1995, Bird 1994, de Pater et al. 1995).

Observations

The Maryland Point 85 foot telescope was used to monitor Jupiter at 1665 MHz beginning on June 29, 1994 and continued through August 24, 19'34. A traditional OFF-ON-OFF method was used for both Jupiter and calibration radio sources. The 29' (FWHM) main beam of the antenna is well behaved at 18 cm, with an aperture efficiency of better than 50 percent at zenith (McClain 1966). The telescope has been operated since 1966 for numerous radio astronomy observations associated with the former Radio Astronomy Branch of the E. O. Hulbert Center for Space Research at the Naval Research Laboratory (e.g. Spencer & Schwartz 1975). Data were collected using a single sense of a circularly polarized feed centered at 1665 MHz. The receiver was a heterodyne mixer with a single-sideband system temperature on the antenna of approximately 100 K. The telescope recorded data every two seconds over a bandwidth of 50 MHz. A 0.1 s time constant was attached to the line just prior to detection and read out using an analog to digital converter under computer control. Twenty samples were averaged and written to disk every two seconds.

Pointing checks anti flux density calibration observations were performed on a number of extra galactic calibrators including 3C273, 3C274, 3C2 79, and 3C286. The calibration of Jupiter was performed relative to the flux density (see Table 1) of the above calibrators established by Baars et al (1977), Waltman (unpublished) and Ott et al (1994). These sources were observed every twenty minutes to correct for various system gain changes as a function of time and telescope zenith angle. Jupiter and the extra galactic calibrators were observed from horizon to horizon or for approximately 9 hours per day.

The telescope ran under remote control of a personal computer. On the days when data were recorded they were scaled to the flux

density that would be observed if Jupiter were at a fixed distance of 4.04 AU from the Earth, This allows a direct comparison with earlier observations from the past, as Jupiter's distance from the Earth varies as a function of orbital period. Jupiter was actually at a distance of approximately 5.1 AU from the Earth during these observations. Using an atmospheric model, the thermal emission component was subtracted to give an estimate of the total synchrotrons flux density. Data were successfully recorded on a total of 21 days.

Thermal emission and beaming curve

Jovian decimetric emission is a combination of synchrotrons emission originating from the relativistic electrons trapped in Jupiter's radiation belts and thermal emission from the planet's atmosphere. A thermal component of approximately 1.12 Jy is calculated from an assumed atmospheric temperature of 330 K at 18 cm (de Pater and Massie 1985).

The synchrotrons radiation component as seen by an observer varies with the planet's rotation. To compare the emission intensity each day a model of the beaming curve is used to determine the average flux for each day. This model is represented by :

$$S = S_0 + S_1 + S_2 \sum A_n \sin\left[n(\lambda + \lambda_n)\right]$$

where S is the total flux density observed normalized to a distance of 4.04 AU, S_0 is the thermal component, S_1 is the mean value of the synchrotrons flux component. λ is the system 111 central meridian longitude of Jupiter. A_n and λ_n are constants for n terms (n=1,2,3) in a Fourier series. S_2 is a scaling factor for the Fourier terms. Even with the de coupling of the S_1 and S_2 terms the model is subject to error if the beaming curve deviates far from the shape implied by the Fourier coefficients. As discussed below this is most likely the case during the week of the impacts. An alternative method would be to simply average the flux from all longitudes each day. The problem with this method is the lack of data each day at all longitudes which would require a 10 hour observation.

For the analysis reported in this paper we used the coefficients of the Fourier series supplied by Klein et al (1995). These were calculated from pre-impact observations by the NASA/JPL Deep Space Network

(DSN) antennas operating at 229S MHz. The DSN observations provided the longest baseline available for the determination of the pre-impact beaming curve coefficients. A previous study indicated the beaming curve coefficients at 229S MHz were similar to measurements at 1400 MHz (Bolton 1991). The coefficients used in our analysis were:

A_1=1.000	λ_1=237.98
A_2=1.061	λ_2=-66.86
A_3=0.190	λ_3= 8.55

Results

Our results indicate an increase in Jupiter's synchrotrons emission occurred during the week of the impacts. Figure 1 shows a 23% increase in Jupiter's flux density between DOY 197-203. Plotted is the sum of the S_0 and S_1 terms described above. The sudden increase appears relatively linear between the start and end times of the impacts. Similar increases were observed at other wavelengths as summarized by de Pater et al. (1995). Relatively large brightness temperature variations appear for short time intervals (hours). An example of the hourly variations is shown in Figure 2. The rise in intensity typically lasts for approximately 30-60 degrees of longitude or 1-2 hours. Similar brightness variations are observed at approximately the same central meridian longitude on consecutive days suggesting a longitudinally constrained variation. The variations result in the beaming curve appearance becoming asymmetric. The asymmetries increase the error in our estimate of the average daily flux especially during the week of the impacts when they are most prevalent. The longitudinal brightening remain detectable until the end of our observations (DOY 220). Their appearance evolves with consecutive Jupiter rotations to lesser amplitude and longer times (i.e. spreading in longitude). The result is a beaming curve distortion which decreases the validity of the inherent assumptions implied by Equation 1. The errors introduced in our daily flux estimates are approximately 5-7% with the maximum occurring during the week of impacts. The week long trend of a flux increase each day appears real although a decrease in the average daily flux on any single day cannot be ruled out.

Figure 3 compares a pre-impact and post-impact beaming curve. Using a polynomial best fit routine the beaming curve coefficients are determined (after subtraction of the thermal component) and the beaming curve is plotted. The pre-impact data was from DOY 182-194 and the post-impact data was from DOY 214-220. The analysis is subject to error since some of the longitudinal asymmetries were present in the post-impact data. These are not represented in Figure 3. To compensate for the asymmetries we averaged multiple rotations to obtain an average flux from each longitude. Days with large asymmetries (during the impact period) have been excluded. The pre-impact and post-impact data were normalized for differences in amplitude of S1 prior to plotting. The results shown in Figure 3 indicate the beaming curve flattened out as a result of the impacts.

Discussion

The increase in the synchrotrons emission is consistent with results reported by other observers (de Pater et al. 1995). Comparison with observations at other frequencies indicates a hardening of the spectrum took place in addition to the increase of flux density, longitudinal brightening and the flattening of the beaming curve reported in this paper (Klein et al. 1995, Bird et al. 1994). These characteristics of the variations are important in determining the physical mechanism(s) responsible for the variations.

The flux density and hardening of the spectrum is consistent with an increase in the rate of inward radial diffusion (Ip 1994). The principal inconsistency with this mechanism is the observation of a flatter beaming curve. An increase in the rate of inward radial diffusion will result in the electron pitch angle distribution becoming more closely confined to the equator (Bolton and Thorne 1995) which would produce the opposite effect on the beaming curve from what was observed. A flatter beaming curve implies a broadening of the pitch angle distribution or a significant decrease in electron energy. A broader pitch angle distribution results in a flatter beaming curve because the intensity variations due to the magnetic field rotating and wobbling around lessen. For illustration consider a simple dipole model where a constant level of emission beamed in all directions originates at all latitudes and longitudes. A completely flat beaming curve would then be observed. An alternative explanation for a flatter beaming curve is electron energy decrease. A decrease in energy would increase the solid angle cone of the

radiation. The cone has a half width in radius defined by $1/\gamma$ with $\gamma=1-v^2/c^2$, where v is the perpendicular velocity of the electron and c is the speed of light. Thus a decrease in energy results in a broader spread of radiation and a flatter beaming curve. A decrease in energy also results in a decrease in the intensity of the emission which was not observed. Another possible explanation for the flatter beaming curve is associated with the location of the longitudinal brightenings. Particles associated with the brightening would be expected to spread in longitude over a few drift periods (about two weeks). If the brightening were to be concentrated in the troughs of the beaming curve then observations during the interim (during the spreading) could indicate a flatter beaming curve. In this scenario, the flattening would not be visible after a few weeks (outside the time period for data in this report). A more detailed analysis of beaming curve data during the impacts is required to compare the locations of the longitudinal brightening and the impacts. Preliminary inspection indicates the impacts occurred somewhat evenly over wide ranges of Jovian longitude as shown in Bolton and Thorne (1995). We therefore expect the longitudinal brightening to be evenly spread between the beaming curve peaks and troughs. We suggest that the flatter beaming curve is associated with a broader electron pitch angle distribution which is also consistent with a hardening of the spectrum and an overall flux density increase.

A localized mechanism directly in the radiation belts is consistent with the above mentioned characteristics and is suggested by the creation of the longitudinal asymmetries in the beaming curve. Bolton and Thorne (1995) discuss the pitch angle scattering as a local mechanism to explain observed changes in the synchrotrons emission. They identify whistler mode waves as a likely scattering mechanism and investigate the sources and amplitudes required to be consistent with the observed synchrotrons emission time variations.

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Table 1

Calibrator Source	Flux density at 1665 MHz
3C273	25 Jy
3C274	184 Jy
3C279	9.45 Jy
3C286	13.6 Jy

Figure Captions:

Figure 1. The intensity of Jupiter's radio emission at 1665 MHz normalized to a distance of 4.04 au. Data points represent daily values of the total flux density including thermal and non-thermal.

Figure 2. An example of the Jupiter beaming curve during the week of the impacts. The data are from July 19 and 20 (DOY 200 and 201) and represent non-thermal emission only. The data have been normalized to adjust the average flux level to facilitate comparison with Figure 3.

Figure 3. Comparison of beaming curves prior to and after the impact of SL-9. The solid line is the pre-impact curve fitted to data from DOY 182-194. The dotted line represents data from the post-impact period, DOY 214-220.

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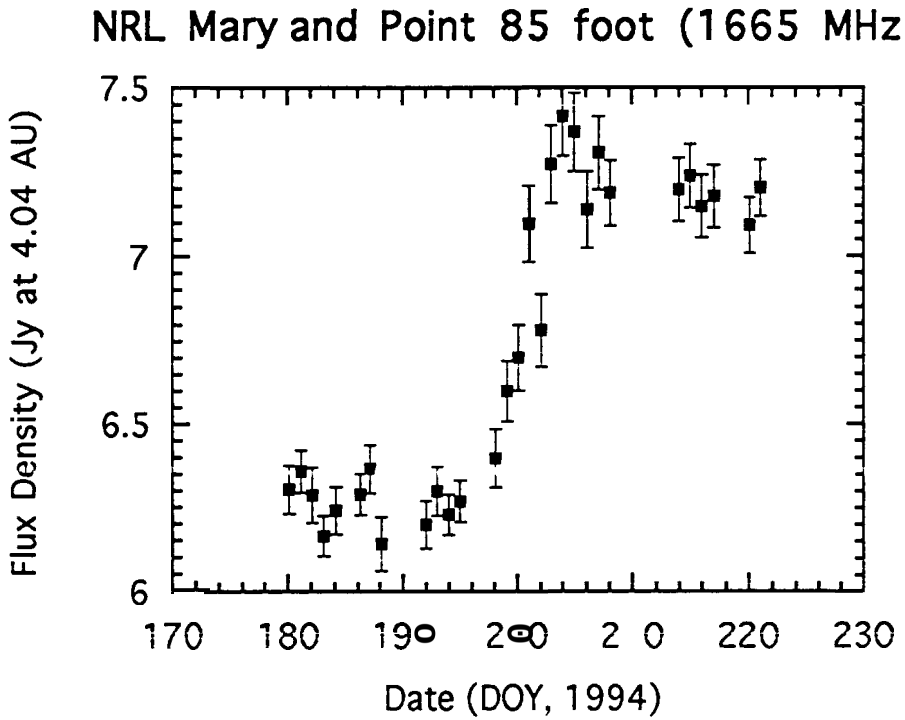
NRL Mary and Point 85 foot (1665 MHz)
Flux Density (Jy at 4.04 AU)
7.5
7
6.5
6
170
180
190
200
210
220
230
Date (DOY, 1994)

Figure 1

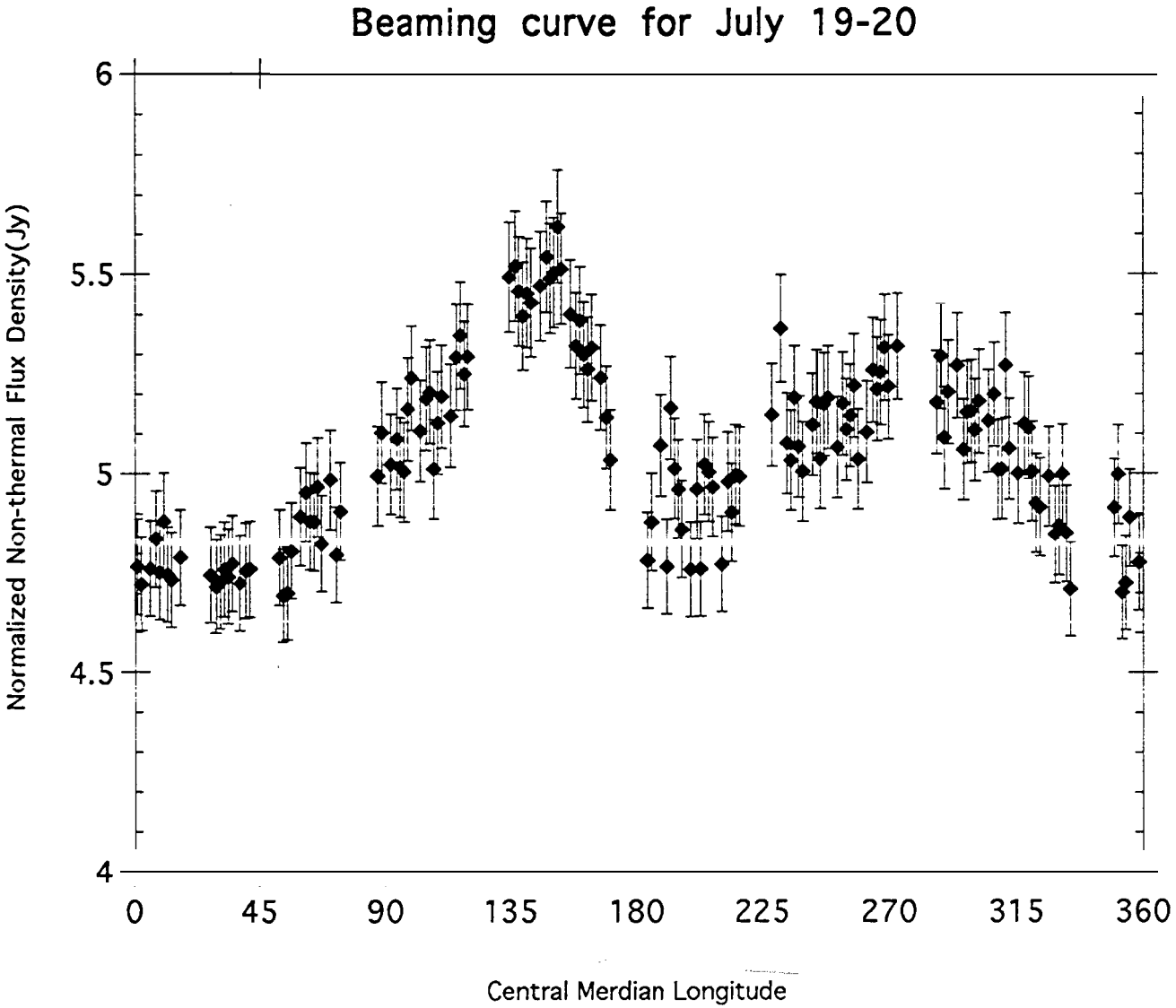
Beaming curve for July 19-20
Normalized Non-thermal Flux Density(Jy)
6
5.5
5
4.5
4
0
45
90
135
180
225
270
315
360
Central Merdian Longitude

FIGURE 2

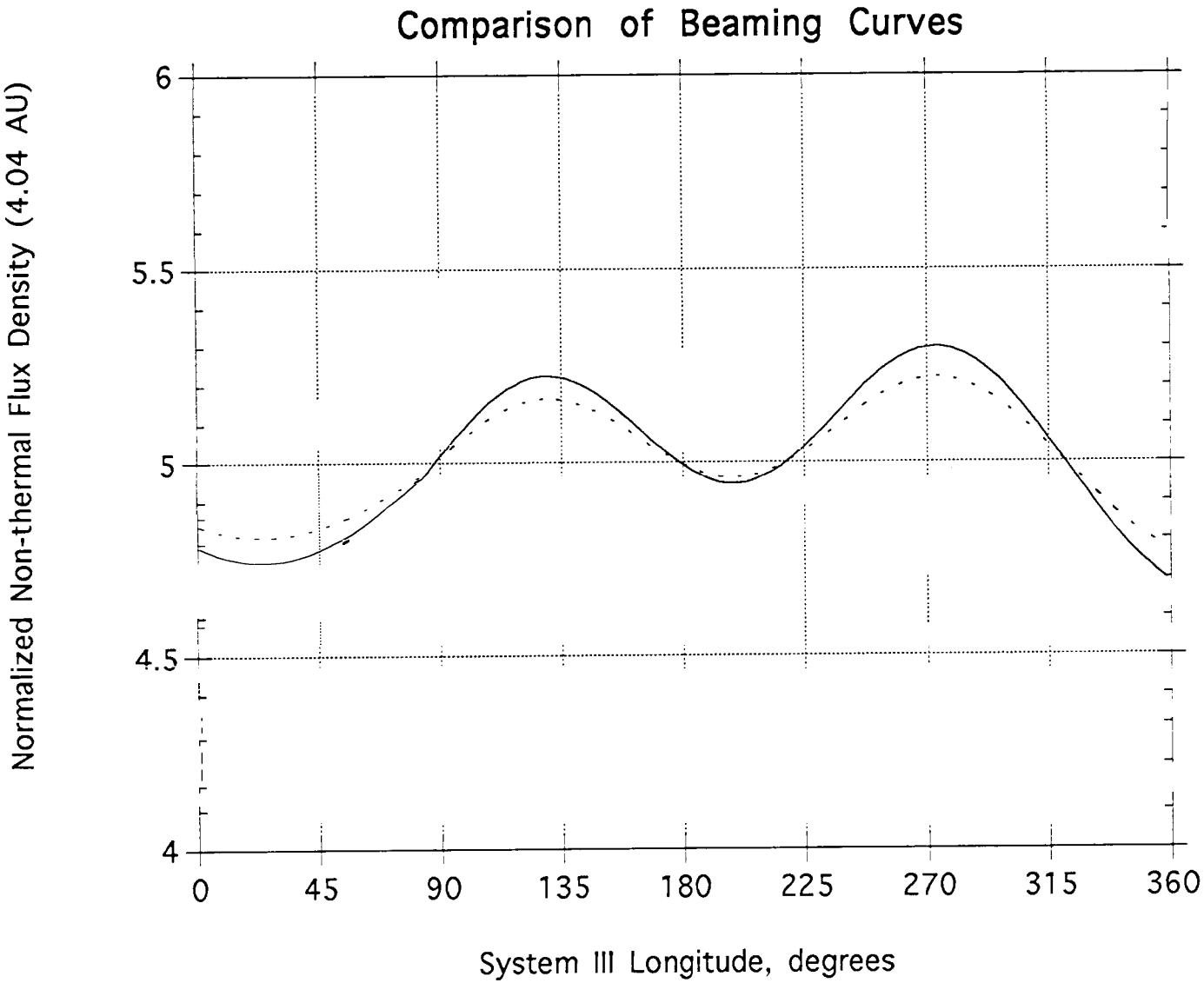
Comparison of Beaming Curves
Normalized Non-thermal Flux Density (4.04 AU)
6
5.5
5
4.5
4
0
45
90
135
180
225
270
315
360
System III Longitude, degrees

Figure 2